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(54) SYSTEME POUR DETERMINER LES DONNEES D'ALIGNEMENT DANS DES CONNEXIONS DE TELECOMMUNICATIONS PAR FIBRES OPTIQUES

(54) SYSTEM FOR THE DETERMINATION OF ALIGNMENT DATA IN OPTICAL COMMUNICATIONS CONNECTIONS

(57)
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(12) (19) (CA) **Demande-Application**

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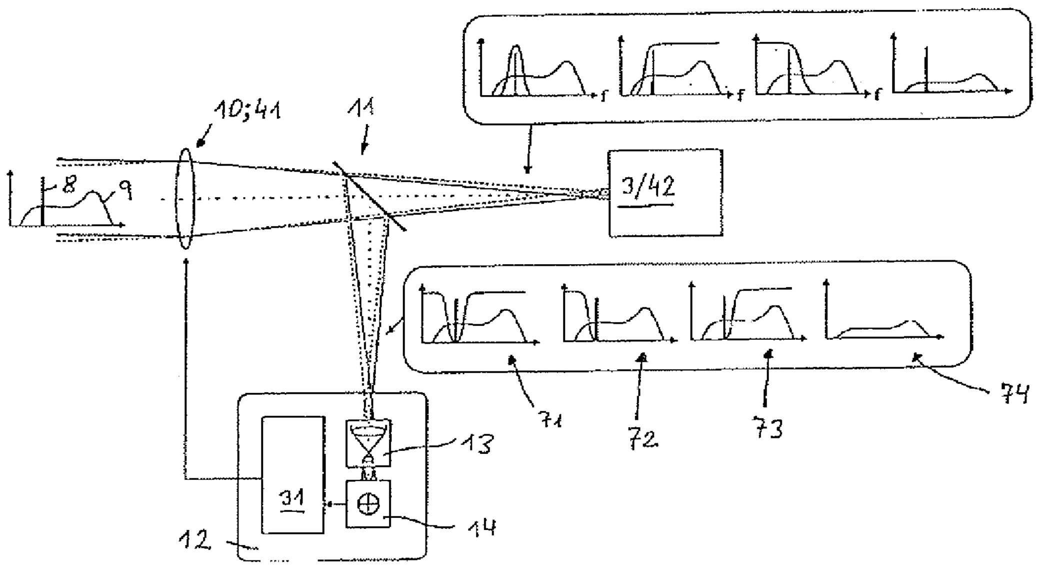

(57) The system is used for determining alignment data in optical communications connections between a receiver and a transmitter remote from the former. The spontaneously emitted output of the optical pre-amplifier in the receiver is used as the output signal for aligning the optical telescopic device of the transmitter and/or the spontaneously emitted output of the optical output amplifier at the transmitter as the input signal for the alignment of the receiving telescope at the receiver. To this end, a filter (11) is provided in order to separate data signals (8) from the respective spontaneously emitted output (9), wherein means (12) are provided for processing this spontaneously emitted output as the output signal for aligning a telescope (10).

ABSTRACT OF THE DISCLOSURE

The system is used for determining alignment data in optical communications connections between a receiver and a transmitter remote from the former. The spontaneously emitted output of the optical pre-amplifier in the receiver is used as the output signal for aligning the optical telescopic device of the transmitter and/or the spontaneously emitted output of the optical output amplifier at the transmitter as the input signal for the alignment of the receiving telescope at the receiver. To this end, a filter (**11**) is provided in order to separate data signals (**8**) from the respective spontaneously emitted output (**9**), wherein means (**12**) are provided for processing this spontaneously emitted output as the output signal for aligning a telescope (**10**).

SYSTEM FOR THE DETERMINATION OF ALIGNMENT DATA IN OPTICAL COMMUNICATIONS CONNECTIONS

FIELD OF THE INVENTION

The invention relates to a system for the determination of alignment data in optical communications connections between a receiver and a transmitter, which is distant from the former and which is provided with an optical output amplifier, wherein the receiver has an optical telescopic device.

BACKGROUND OF THE INVENTION

One of the main problems with optical communications connections, for example between satellites (optical intersatellite links, OISL) is the exact alignment of the transmitting and receiving telescopes (pointing, acquisition, tracking, PAT) with each other *(S. Arnon, N. S. Kopeika, Proc. IEEE, 85, 1646 to 1661, 1997)*. Rough alignment is performed by means of the orbital data of the satellites. In concepts published up to now, the determination of the correction data for an exact alignment (pointing), or respectively for following (tracking), is accomplished either with the aid

of incidental strong laser sources (beacon laser), or by tapping of a portion of the optical output which transmits the data signal. The disadvantage of the first mentioned system lies in that additional components, and therefore additional energy, mass, complexity and costs are required. Moreover, an exact alignment of the beacon telescope parallel with the optical axis of the transmitting, or respectively receiving telescope is required. With the second method, which can only be employed on the receiving end, while otherwise the system parameters and the transmission quality remain the same, it is necessary to increase the output of the modulated data signals, so that technological limits are rapidly reached.

OBJECT AND SUMMARY OF THE INVENTION

It is therefore the object of the invention, which is described in what follows, to create a novel system of this type which is less elaborate.

In accordance with the invention, this object is attained by means of the characteristics disclosed in claim 1. One advantage of the system in accordance with the invention is that this method is not only suitable for communications between two satellites, but also for the optical free-space transmission in the atmosphere.

Advantageous embodiments of the invention are recited in the dependent claims.

The invention will be explained in greater detail in what follows by means of examples shown in the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic representation of a first embodiment of a system in accordance with the invention with a receiver and a transmitter located a distance away,

Fig. 2 shows the spectral output density of the data signal in such a system,

Fig. 3 is a schematic representation of different embodiments of the system with a wavelength-dependent beam splitter,

Fig. 4 shows a detail of a further embodiment of the system in accordance with the invention,

Fig. 5 shows a duplex system with a single transmitter/receiver telescope in accordance with the invention, and

Fig. 6 shows a duplex system in accordance with the invention with separate transmitter and receiver telescopes.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1 shows a transmitter **2** provided with an optical output amplifier **1**, and a receiver **4** having a pre-amplifier **3**. With this embodiment, the spontaneous emission **5** and/or **6** unavoidably transmitted by the optical output amplifier **1** of the transmitter **2** and/or by the optical pre-amplifier **3** of the receiver **4**, i.e. the so-called amplified spontaneous emission (ASE), which is always present in addition to the data signal **7**, is used for PAT purposes. Because of this it is neither necessary to provide separate energy and hardware, and therefore mass, complexity and costs, for beacon lasers, nor is it necessary to split off output from the data signal **7**, which is very weak anyway, at the receiver for PAT purposes. The elaborate adjustment of the beacon telescope parallel with the transmitter, or respective receiver telescope can also be omitted. The transmitter **2** of course includes an optical telescopic device **21** and an arrangement **22** for generating the optical message signal, and the receiver accordingly also has an optical telescopic device **41** and an arrangement **42** for processing the optical reception signal.

Since, in contrast to terrestrial fiber-optical networks for optical communications, intermediate amplifiers naturally cannot be used with optical communications by means of optical free-space links, the optical transmission output alone must be sufficient for establishing the connection with a required bit error probability. One possibility for generating the transmission output required for this reason is the optical amplification of the modulated light of lasers with low output power at the transmitter. The existence of perfected optical traveling wave amplifiers, for example erbium-doped fiber amplifiers, EDFAs *(J. C. Livas et al., Proc. SPIE, vol. 2381, 38 to 47, 1995)* of a wave length of 1.55 μm is of benefit for the present invention, as well as the pre-amplifiers used to increase the sensitivity of the receiver *(J. C. Livas et al., Proc. SPIE, vol. 2381, 38 to 47, 1995)*.

Fig. 2 shows the spectral output density S(f) **8** of the data signal **7**, as well as the spectral output density of the amplified spontaneous emission NASE **9** of the optical output amplifier **1** at the input of the receiver **4**. At the same time, **9** represents the

spectral output density of the spontaneous emission **6** radiated by the optical pre-amplifier **3**, which can also be encountered at the output of the transmitter **2**.

Fig. 3 shows a possible system realization containing, inter alia, an optical telescopic device **10**, a wavelength- dependent or polarization-dependent beam splitter **11** and a PAT system **12**, wherein the latter can contain as components, for example, an angle-amplifying optical system **13**, a 4-quadrant detector **14** and an electronic control device **31** for telescope alignment. The separation of the data signal and the PAT signal can take place not only via the wavelength, but also via the polarization. Since the wavelength is reversely proportional to the frequency, the terms "wavelength-dependent" or "polarization- dependent" are synonymous in this connection. A beam splitter is employed in both cases, which lets light through or reflects it as a function of the polarization or of the wavelength. The ASE output is spectrally wider by orders of magnitude than the data signal, so that a separation by means of the wavelength is easily possible. Furthermore, the data signal typically exists in a single polarization, while the ASE output occupies both orthogonal polarizations. This makes a separation by means of the polarization easily possible.

Fig. 4 shows a modified version of the PAT system **15** which, besides the components from **Fig. 3**, additionally contains a waveguide bundle, for example a monomode optical fiber bundle **16**, and a CCD element (charge-coupled device) **17**, which is connected to an electronic control device **18** for the telescope alignment.

Besides the desired output signal, which is amplified in respect to the input, optical travelling wave amplifiers emit background light, i.e. the mentioned amplified spontaneous emission (ASE), which has two properties which are important for understanding the invention:

1. The ASE output **5, 6, 9** is spectrally wider by orders of magnitude than the data signal **7 (Fig. 1)** or **8 (Fig. 3)**. Per spatial mode, the spectral output density N_{ASE} **9 is**

$$N_{ASE} = hf(G - 1)n_{sp}, \qquad \text{(A)}$$

wherein hf is the energy of a photon of the considered frequency, G is the (output) amplification of the optical amplifier, and n_{sp} is the (frequency-dependent) spontaneous emission factor. With high-output EDFAs, which are now available, n_{sp} lies between 1 and 3.2. Because of the broadband character of the ASE output **5, 6, 9** in comparison with the data signal **7, 8**, it is possible to perform an almost complete

spectral separation of the received data signal **7** and the ASE output **5**, **6** with the aid of wavelength-dependent beam splitters **11**. Because of this, the entire output of the data signal is available for data transmission, while the ASE output **9** (**Fig. 2**), or portions thereof, can be used for the PAT system. In accordance with the invention, a separation of the signal from the ASE output is also possible by means of the polarization properties of the two optical fields. Similar conditions apply for the ASE output of the receiver at the associated transmitter.

2. Unless appropriate spatial filtering is performed, the ASE output can be found in all spatial modes of the optical system, so that in general the equation (A) needs to be multiplied by the number of modes present. In the actual OISL, however, the number of the actually emitted modes, both of the transmitter ASE output **5** as well as the receiver ASE output **6**, lies between **1** and **2**, because diffraction of the optical telescopic device of the transmitter **2**, as well as that of the receiver **4**, is made as limited as possible.

Since the ASE output occupies the same spatial modes as the data signal, the same propagation conditions apply to both. The lacking chronological coherence of the ASE output is not important for this. At the receiver it is therefore possible in a simple way to make a first estimate of the ASE output of the transmitter. Analogous considerations apply to the estimate of the ASE output of the receiver pre-amplifier at the transmitter. If the diameters of the telescopes at the transmitter and the receiver are designated as DTX and DRX, the communications distance, which is large in respect to the telescope diameter, as R, and the wavelength of the transmitter as , the fraction of the ASE output density, which is coupled into the receiver system from the transmitter, can be estimated as

$$N_{ASE,RX} \approx [D_{RX} D_{TX} / R\lambda]^2 \, hf(G - 1) n_{sp} \qquad \text{(B)}$$

Realistically assuming an erbium-doped output amplifier at the transmitter (λ = 1.55μm), with G = 45dB and a noise factor of F = 6dB, the diameter of a transmitter telescope as well as a receiver telescope of 10 cm and a transmission distance of, for example, 6000 km, $N_{ASE,RX}$ results as $9{,}3 \cdot 10^{-21}$ W/Hz. If an optical bandwidth of 20 nm of the PAT system is assumed (the entire amplification bandwidth of an EDFA is approximately 30 nm), an output for PAT purposes of $2{,}4 \cdot 10^{-8}$ W (= -46 dBm) results, which appears to be sufficient in comparison with other systems *(R. Cockshott, D. Puril, Proc. SPIE, vol. 2381, 206 to 214, 1995)*.

Fig. 3 shows a possible realization of the system for the case of using the transmitter ASE output at the receiver of an OISL. The impinging optical wave is focused by means of an optical telescopic device **10**. As the schematic representation of the spectra in **Fig. 3** shows, the majority of the ASE output is branched off by means of a generally known frequency-dependent beam splitter **11**, as indicated in **Fig. 3**, with a band-pass/band- stop characteristic, or also with low bandpass/high bandpass characteristics *(N. Kashima, "Passive Optical Components for Optical Fiber Transmission", Artech House, Boston, 1995)*. This output can be conducted, for example, to a 4-quadrant detector **14** in accordance with the prior art via an angle-amplifying optical system **13**, for example a telescope, which is used for increasing the angular resolution of the PAT system **12**, wherein a CCD sensor, or respectively discrete photodetectors, can also be employed. The control signals for the alignment of the optical telescopic device **10**, or respectively for its tracking, are obtained from the output signals of the 4-quadrant detector *(W. Auer, SPIE Milestone Series, vol. MS 100 (D. Begley, ed.), 275 to 280, 1994, and D. M. Southwood, Proc. SPIE, vol. 1635, 286 to 299, 1992)*.

It is also remarkable that the PAT system in accordance with the invention can be employed, with small modifications, under strong background illumination. The background radiation of Venus, for example, is approximately $4 \cdot 10^{-25}$ W/Hz per spatial mode, that of the sun approximately $4 \cdot 10^{-20}$ W/Hz per spatial mode *(W. R. Leeb, Applied Optics, 3443 to 3449, 1989)*. Since these sources emit simultaneously in many modes, the total background radiation is greater than the ASE output and would impair the PAT system. The use of a mode filter, which limits the received radiation to one mode, provides a remedy here. The ASE output received for PAT purposes is therefore only insignificantly weakened, because the ASE output only occupies **1** to **2** spatial modes anyway, as already mentioned above. The multi-mode background radiation, however, is greatly attenuated and in accordance with this realization lies in its output below the ASE output.

Fig. 4 shows a possible realization of the processing system for the ASE output used in this case. Instead of a direct illumination of a 4-quadrant detector, a monomode waveguide bundle or optical fiber bundle **16** is used in combination with, for example, a CCD element **17**. This optical fiber bundle **16**, which for example can be an integrated optical device or an optical fiber bundle, has been inserted between the angle-amplifying optical device and the detector, and operates as a mode filter. The multi-mode background radiation is limited to one mode by the coupling in monomode fibers, and in its output therefore lies below the ASE output of the

transmitter coupled into the receiver which, as mentioned above, only occupies one or two modes anyway and, in comparison with the background radiation, is therefore only weakly attenuated when being coupled in. A CCD element is represented in **Fig. 4** as the detector, however, a 4-quadrant detector, a focal plane array, or discrete photodiodes could also be employed. The mode filter need not necessarily be produced by means of optical fiber technology, since every type of optical waveguides, for example as integrated optical devices, is suitable for this.

Therefore the presence of optical traveling wave amplifiers in the transmitter and/or the receiver is characteristic for the system in accordance with the invention for determining the alignment data in an optical free-space transmission system, wherein the transmitter, or respectively receiver telescope is aligned or tracked by means of the ASE output. For example, erbium-doped fiber amplifiers, EDFA, in a wavelength range of 1.55 µm, Nd- or respectively Pr-doped fiber amplifiers of a wavelength of 1.3 µm, or DC-NDFA at 1.06 µm, or every other optical traveling wave amplifier, can be employed. If such an amplifier is provided, the alignment data for the respectively oppositely located telescope can be obtained by means of the ASE output transmitted by the traveling wave amplifier.

The duplex system in accordance with **Fig. 5** has two terminals **51** and **56**, each with an optical telescopic device **511**, or respectively **561**, to each of which a transmitter unit **512**, or respectively **562**, and a receiver unit **513**, or respectively **563**, are connected. The two optical message-transmitter units **512** and **562** are each provided with an optical amplifier **514**, or respectively **564**, and/or the two optical message-receiver units **513** and **563** are each provided with an optical pre-amplifier **515**, or respectively **565**. In accordance with the present invention, not only is the transmitter signal **52** transmitted by the optical telescopic device **511** of the terminal **51**, and the transmitter signal **57** by the optical telescopic device **561** of the terminal **56**, but also transmitted are an ASE output **53** of the optical transmission amplifier **514** and/or an ASE output **54** of the optical pre-amplifier **515** of the terminal **51**, as well as an ASE output **58** of the optical transmission amplifier **564** and an ASE output **59** of the optical pre-amplifier **565** of the terminal **56**.

The duplex system in accordance with **Fig. 6** has two terminals **61** and **66**, each with a transmitter optical telescopic device **611**, or respectively **661**, and a receiver optical telescopic device **621**, or respectively **671**. Respectively one transmitter unit **612**, or respectively **662**, is connected to the transmitter optical telescopic device **611**, or respectively **661**, and a receiver unit **613**, or respectively **663**, is connected to the

receiver optical telescopic device **621**, or respectively **671**. The two optical message transmitter units **612** and **662** are each provided with an optical amplifier **614** and **664**, and the two optical message receiver units **613** and **663** are each provided with an optical pre- amplifier **615**, or respectively **665**. Therefore, in accordance with the present invention, not only is the transmitter signal **62** transmitted by the optical telescopic device **611** of the terminal **61**, and the transmitter signal **67** of the optical telescopic device **661** of the terminal **66**, but also an ASE output **63** of the optical transmitter amplifier **614** of the terminal **61**, and an ASE output **64** of the optical pre-amplifier **615** and/or an ASE output **68** of the transmission amplifier **664** and an ASE output **69** of the pre- amplifier **665** of the terminal **66**.

In **Figs. 5** and **6**, the arrangements **523** and **623** are intended as transmitters for an optical message signal A, the arrangements **578** and **678** as transmitters for an optical message signal B, the arrangements **504** and **604** as receivers for an optical data signal B and the arrangements **509** and **609** as receivers for an optical data signal A.

Since such optical amplifiers, or respectively pre- amplifiers are provided in the terminals **51**, **56** (**Fig. 5**) and **61**, **66** (**Fig. 6**), it is possible to receive the alignment data for the respectively oppositely located telescope by means of the ASE output transmitted by the traveling wave amplifier. This means that, with the availability of one of the amplifiers **514** or **515**, or respectively **564**, or respectively **614** or **615**, the alignment data for the receiving telescope **561**, or respectively **661** and **671** in the opposite terminal can be obtained and, with the availability of one of the amplifiers **564** or **565**, or respectively **664** or **665**, the alignment data for the transmitting telescope **511**, or respectively **611** and **621** in the opposite terminal can be attained.

In all of these cases it is important that the ASE output of the optical traveling wave amplifier is not suppressed by technical measures, for example filtered, so that it is actually transmitted by the transmitter, or respectively receiver, such as was explained above by means of **Figs. 5** and **6**. In **Fig. 5** a system is represented in which the transmitter and receiver use the same telescope **511**, or respectively **561**. In contrast thereto, **Fig. 6** represents a system, in which the transmitter and the receiver use separate telescopes **611**, **621**, or respectively **661**, **671**. The systems differ from the simplex system of **Fig. 1**, in which an optical data transmission takes place in only one direction. In case the ASE output is used for PAT purposes, no additional telescope is required in all these cases for transmitting, or respectively receiving, the tracking signal. This is in contrast to conventional systems with beacon

lasers, in which often special telescopes are present for this purpose. If respectively only one optical amplifier is employed in the communications terminals, either a transmission amplifier or a pre-amplifier, in a duplex system (**Figs. 5** and **6**) both terminals can still always be aligned by means of the ASE output, since at least one amplifier, which transmits an ASE output, is still located at each end of the transmission path. But in a simplex system only one of the communications terminals can be aligned by means of the ASE output if one amplifier fails.

Fig. 3 also shows other realization of the system, wherein in accordance with the first variation **71** the beam splitter has a band-pass/band-stop characteristic in such a way that a narrow frequency range around the data signal is passed, and the remaining ASE output is reflected. In the further variations **72** and **73**, a beam splitter with high band-pass/low band-pass characteristics is used in such a way that, either in accordance with the one variation **72**, the range of low frequencies is reflected and the remainder is passed or, in accordance with variation **73**, the opposite takes place, because such beam splitters are easier to realize, but wherein the output available for PAT purposes is also less than with variation **71**. The fourth variation relates to the use of a polarization-dependent beam splitter. In this case, use is made of the effect that the data signal normally only takes on one polarization state, but the ASE output is evenly distributed over both possible polarization states. With a polarization-dependent beam splitter it is therefore possible to separate half the ASE output from the data signal and from the other half of the ASE output.

WHAT IS CLAIMED IS:

1. A system for the determination of alignment data in optical communications connections between a receiver (**4**) and a transmitter (**2**), which is distant from the former and which is provided with an optical output amplifier (**1**), wherein the receiver (**4**) has an optical telescopic device (**41**),

characterized in that

the spontaneously emitted output (**5**) of the optical output amplifier (**1**) on the receiver end is used as the input signal for the alignment of the optical telescopic device (**41, 10**) of the receiver (**4**).

2. A system for the determination of alignment data in optical communications connections between a receiver (**4**) and a transmitter (**2**), which is distant from the former and which is provided with an optical telescopic device (**21**), wherein the receiver (**4**) has an optical pre-amplifier (**3**),

characterized in that

the spontaneously emitted output (**6**) of the optical pre- amplifier (**3**) is used in the receiver (**4**) as the input signal for the alignment of the optical telescopic device (**21**) of the transmitter (**2**).

3. A system for the determination of alignment data in optical communications connections between a receiver (**56, 66**) and a transmitter (**51, 61**), which is distant from the former, wherein the transmitter is provided with an optical output amplifier and an optical telescopic device and/or the receiver is provided with an optical telescopic device and an optical pre-amplifier,

characterized in that

the spontaneously emitted output (**59, 69**) of the optical pre-amplifier (**565, 665**) is used in the receiver (**56, 66**) as the input signal for the alignment of the optical telescopic device (**511, 611, 621**) of the transmitter (**51, 61**), and/or the spontaneously emitted output (**53, 63**) of the optical output amplifier (**514, 614**) at the receiver end is used as the input signal for the alignment of the receiving telescope (**561, 661, 671**) of the receiver (**56, 66**).

4. The system in accordance with one of claims **1 to 3**,
characterized in that
a filter (**11**) is provided for separating the data signals (**8**) from the respective spontaneously emitted output, and that means (**13, 14, 31; 13, 16, 17, 18**) are provided for processing this spontaneously emitted output as the output signal for aligning a telescope (**10**).

5. The system in accordance with claim **4**,
characterized in that
this filter (**11**) is a wave-dependent beam splitter or a polarization filter.

6. The system in accordance with claim **4** or **5**,
characterized in that
a PAT installation (Pointing, Aquisition, Tracking) (**12**) with an angle-amplifying optical system (**13**) is provided in order to receive the output, which results from the spontaneously emitted output (**5**) of the opposite side, filtered out by means of this filter (**11**), and that the PAT installation (**12**) includes a detector (**14, 17**) and an electronic control device (**31, 18**) for processing this filtered-out output.

7. The system in accordance with claim **6**,
characterized in that
this detector is a 4-quadrant detector (**14**) or a CCD detector (charge-coupled device) (**17**).

8. The system in accordance with claim **6**,
characterized in that
a focal plane array or discrete photodiodes are used as detectors.

9. The system in accordance with one of claims **1** to **8**,

characterized in that

an optical traveling wave amplifier, for example an optical semiconductor amplifier, an erbium-doped fiber amplifier, or an Nd- or Pr-doped fiber amplifier is provided in the transmitter.

10. The system in accordance with one of claims **1** to **9**,

characterized in that

spatial filtering by means of optical monomode waveguides (**6**) takes place for suppressing interfering background illumination.

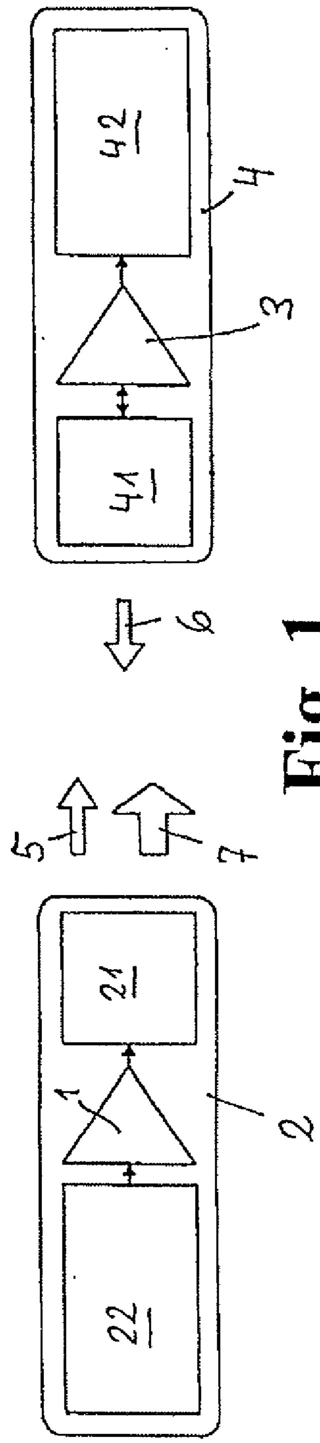

Fig. 1

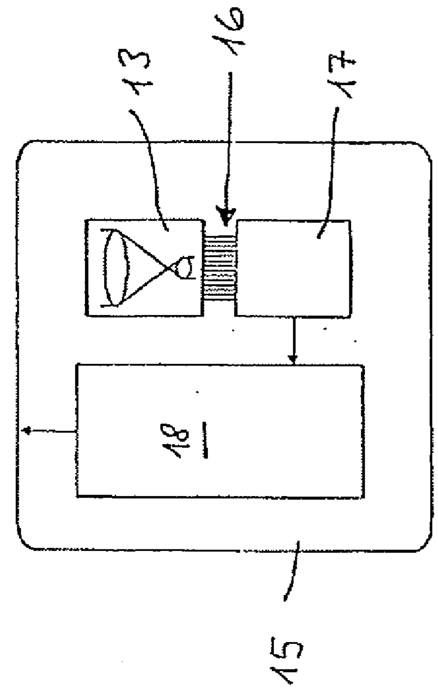

Fig. 4

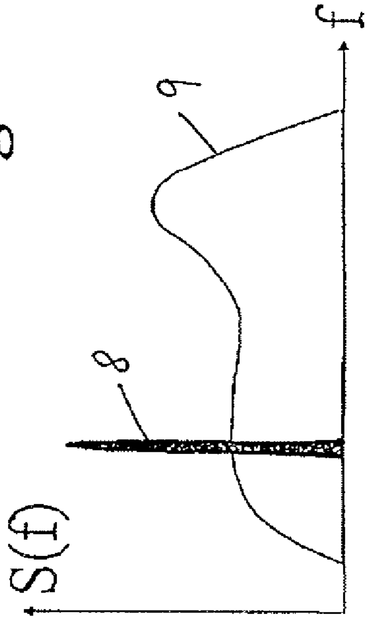

Fig. 2

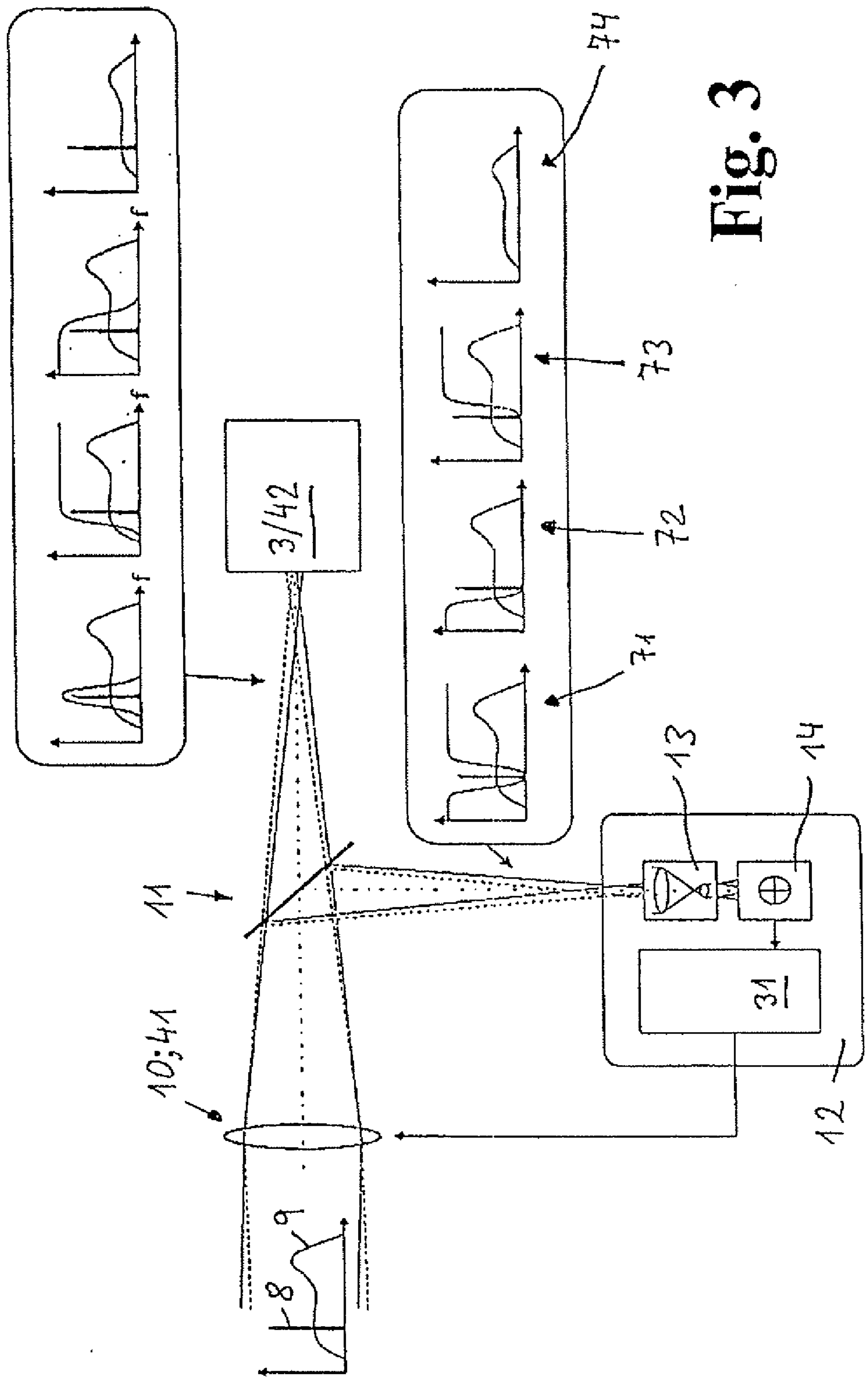

Fig. 3

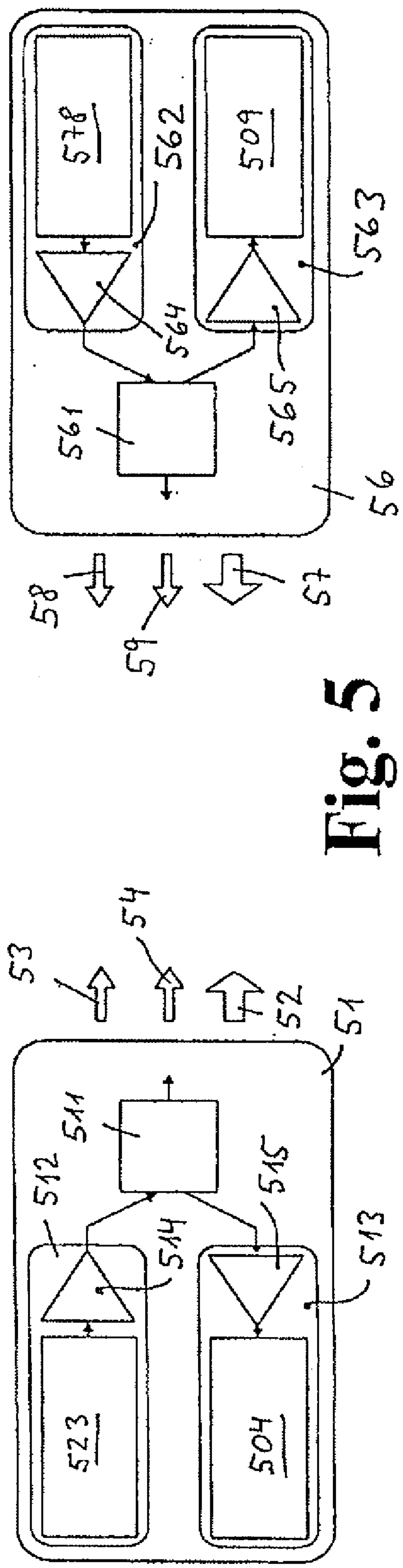

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Fig. 5

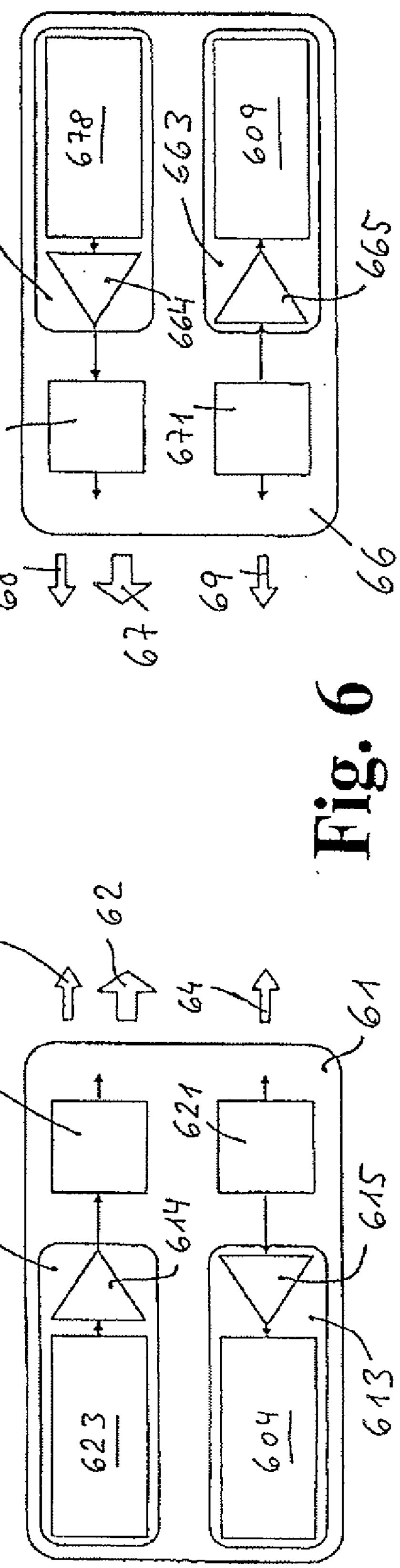

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Fig. 6